

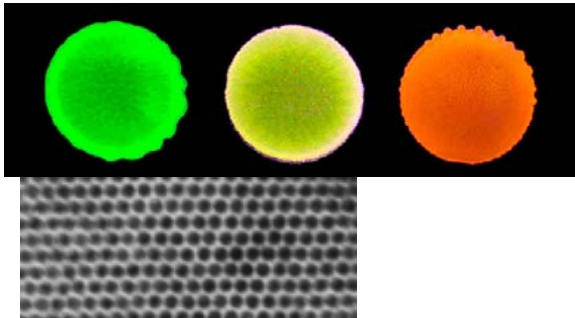


# Center for Integrated Nanotechnologies: Nanophotonics & Nanoelectronics



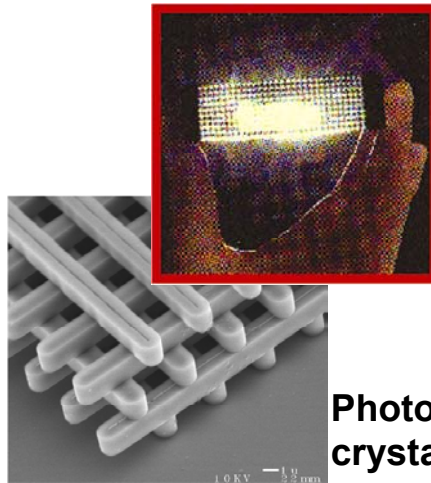
Exploring new frontiers in photonics and electronics

Novel materials



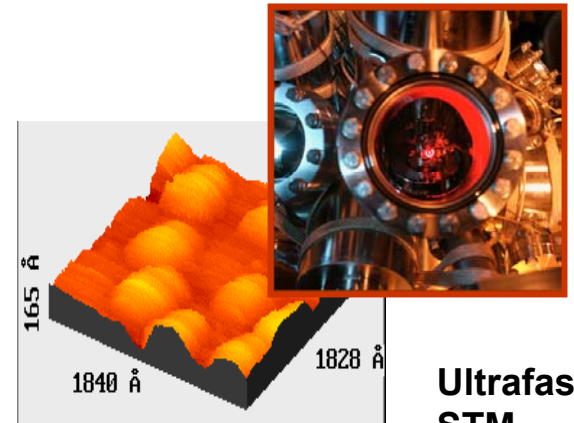
Quantum dot  
solids

Novel phenomena



Photonic  
crystals

Novel tools



Ultrafast  
STM

**SNL**

**Jerry Simmons**  
**Mike Sinclair**  
**Mike Lilly**  
**Shawn Lin**  
**John Reno**  
**Joel Wendt**

**LANL**

**Victor Klimov**  
**Toni Taylor**  
**Darryl Smith**  
**Stuart Trugman**  
**Chris Hammel**



# Outline



- **Thrust definition for Nanophotonics & Nanoelectronics**
- **Topics of interest**
  - **Current activities at Los Alamos and Sandia**
  - **Future directions**
- **How collaborations might work**



# Nanophotonics & Nanoelectronics: Thrust Description



**Complex Functional  
Materials**

**Nano-mechanics**

**Nano-bio**

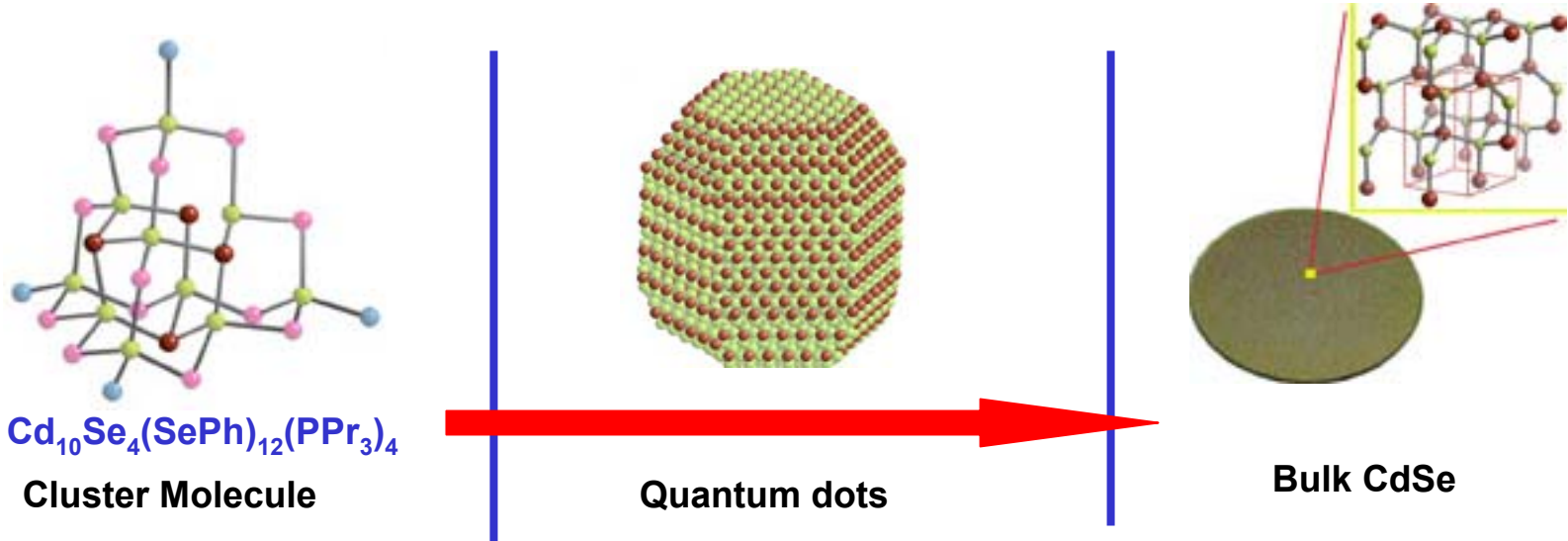
- **Understanding electronic, magnetic, and optical phenomena at the nanoscale**
  - Inorganic and organic photonic, electronic, and magnetic nanostructures
  - Hybrid inorganic/organic nanocomposites and complex interfaces
- **New concepts for controlling electronic and optical properties of nanomaterials**
  - Tailored electronic wave functions and cooperative interactions
  - Tailored density of photon states and photonic interactions
  - Interplay between tunable electronic and photonic spectra/interactions

**Theory**

**Novel instrumentation**



# Tailored Electronic/Optical Properties via Quantum-Size Effect



100 atoms

100,000 atoms

Nano-fabrication:

Colloidal dots

Epitaxial dots

Nano-mechanics:

Structural reconstruction

Strain effects

Theory:

Quantum chemistry

Effective mass

Characterization: TEM, Scan-Probes, Optical spectroscopies (time-resolved, single-dot,

...)

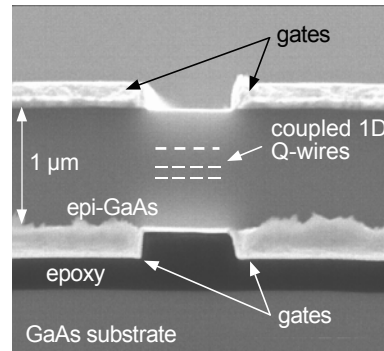
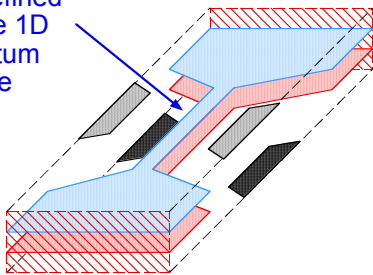


# Novel Nanoelectronic Phenomena Arising from **Tailored Electron-Electron Interactions**

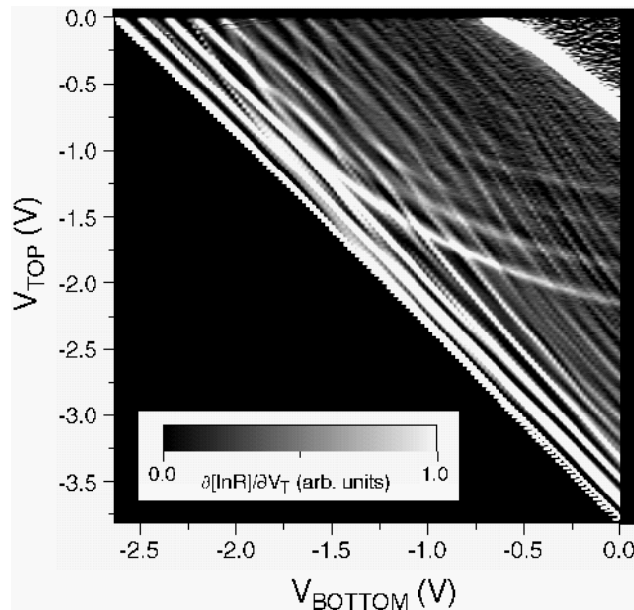


**Coupled 1D Quantum wires:** unprecedented control over individual 1D states.

gate-defined double 1D quantum wire



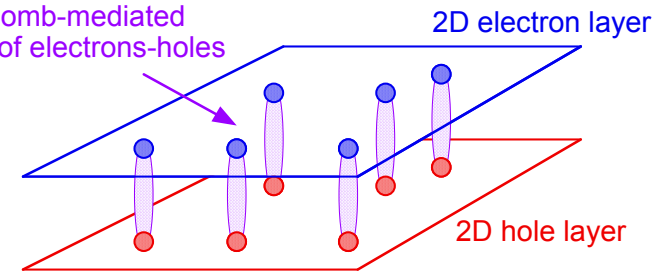
**Energy spectroscopy** of interacting 1D wires.



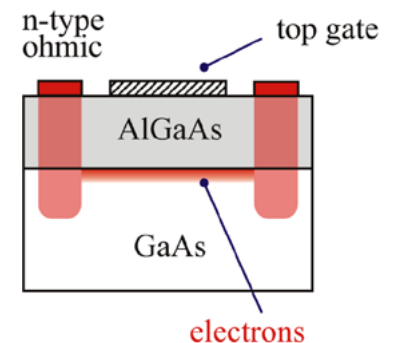
**FUTURE DIRECTIONS:** Luttinger liquids; quantum computing

**FUTURE DIRECTIONS: Coupled electron-hole bilayers** - Coulomb coupling leads to Bose condensation of e-h pairs, a novel superfluid or **“excitonic superconductor”** achieved by “engineering” of particle interactions.

Bosons formed by Coulomb-mediated pairing of electrons-holes

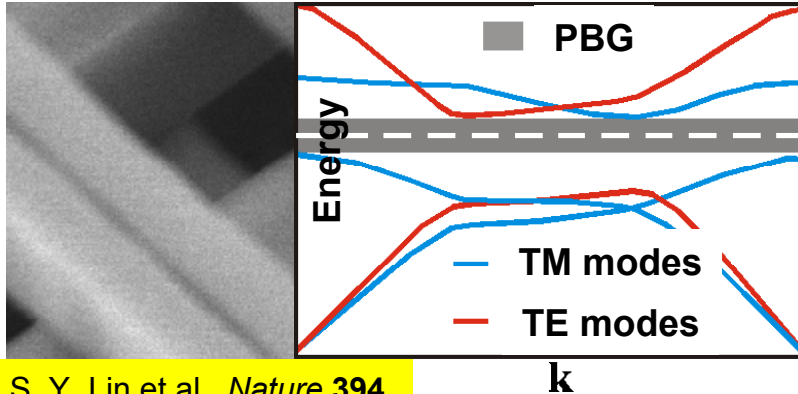


**undoped heterostructure:** Ultra-low disorder

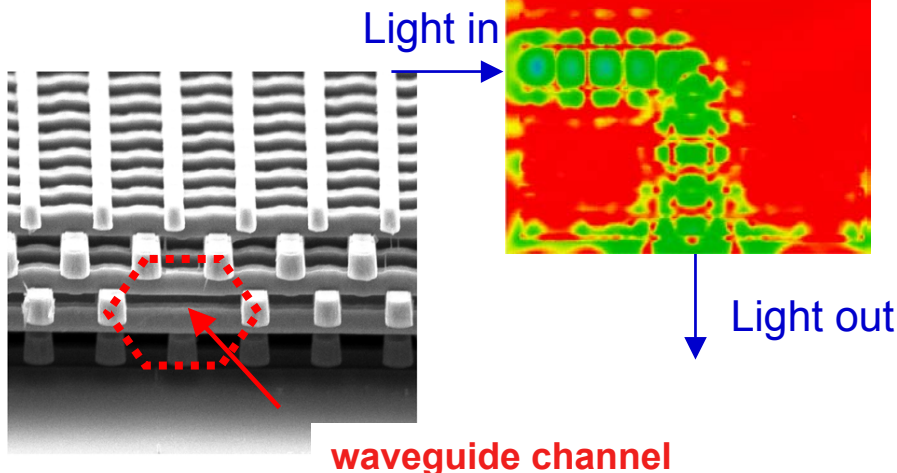


# Photonic Crystals and Photonic Fibers: Tailored Photonic Interactions

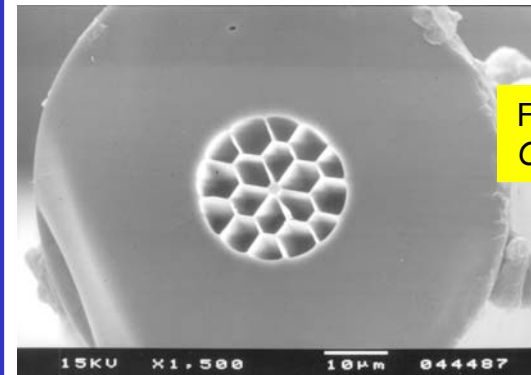
- Photonic crystals: optical interconnects, filters, switches, microcavities, LEDs, etc.



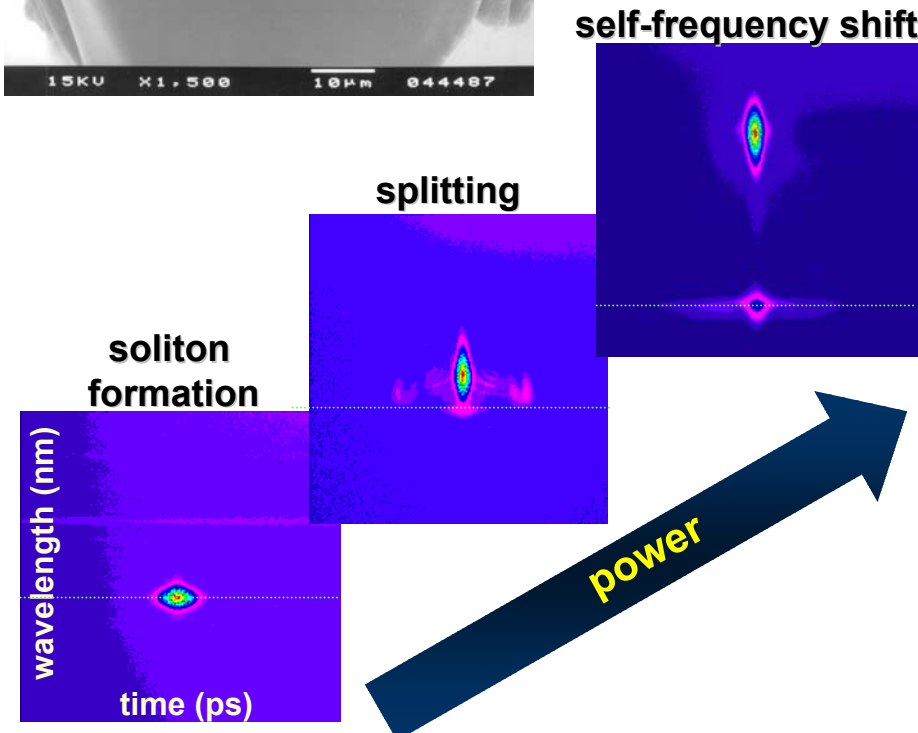
S. Y. Lin et al., *Nature* **394**, 251 (1998)



- Photonic fibers: high-speed telecom, nonlinear optics



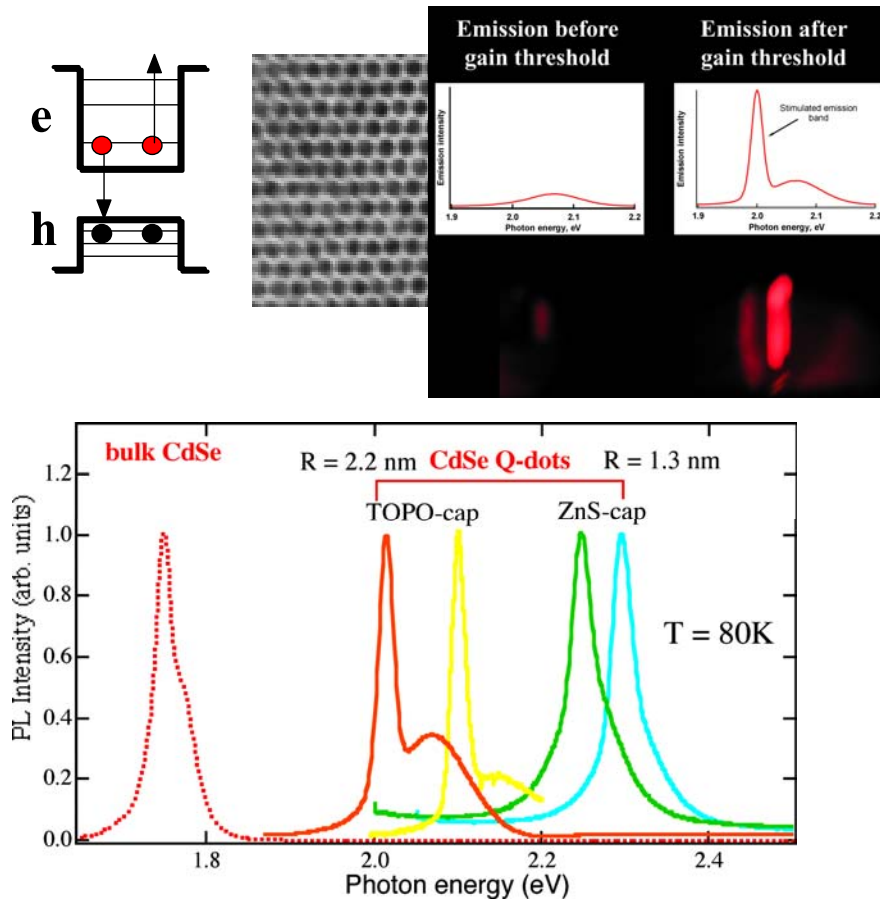
F. G. Omenetto et al.,  
*Opt. Lett.* **26**, 1158 (2001)





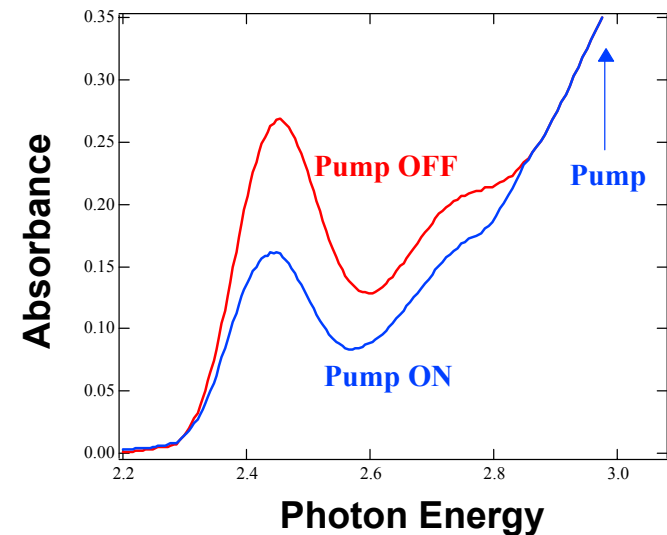
# Nanocrystal Q-dots: Nanoscale Building Blocks with Tunable Optical Spectra

- Optical amplification and lasing in NQD solids



V. Klimov et al., *Science* **287**, 1011 (2000), *Science* **290**, 314 (2000)

- Resonant optical nonlinearities in NQD solids

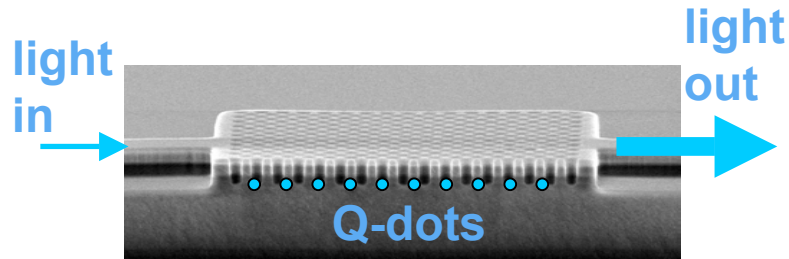


optical modulation/switching,  
optical logic, light steering, etc.

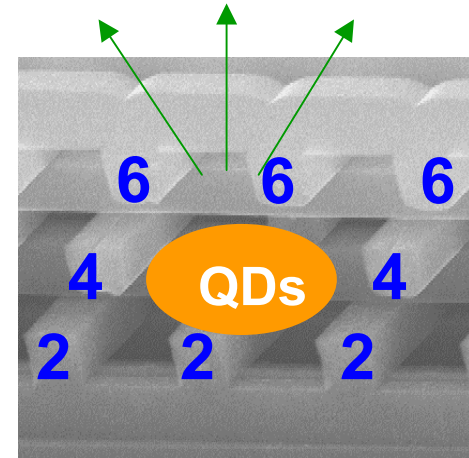
B. Kraabel et al., *Appl. Phys. Lett.* **78**, 1814 (2001)

# FUTURE DIRECTIONS: Novel Photonic Devices via Combining Q-dots and Photonic Structures

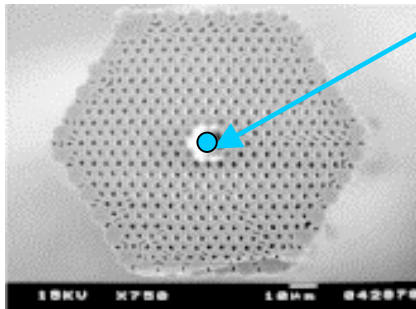
- Micro-lasers and amplifiers based on QDs inserted in cavities in photonic crystals



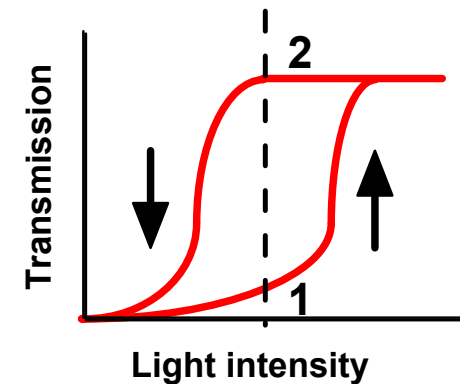
Optical amplification in QDs in 2D photonic crystals



- Nonlinear-optical elements based on QDs in photonic fibers and photonic crystals



Quantum dots embedded in core of holey fiber



Bi-stable switching due to nonlinearity & positive feedback

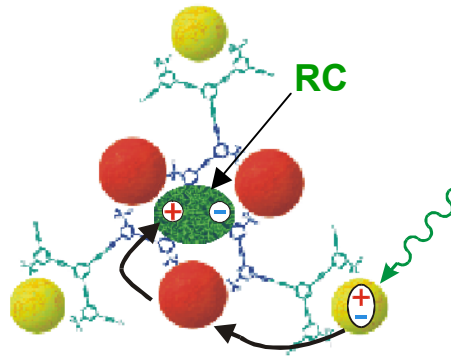
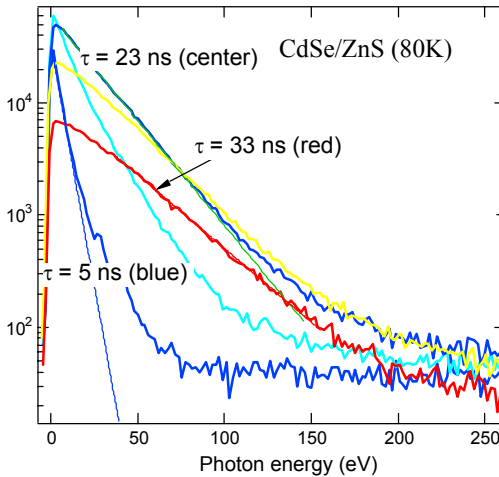
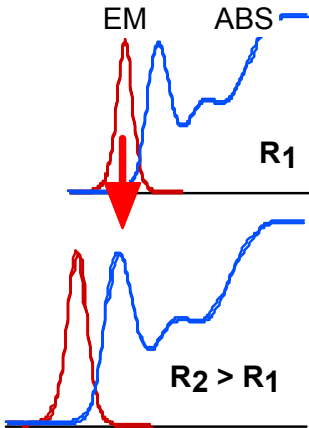
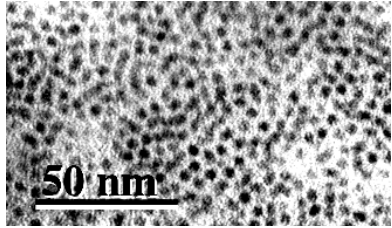




# FUTURE DIRECTIONS: Novel Optical Properties via Near-Field Coulomb Interactions



## •Exciton transport in Q-dot assemblies



Nano-chemistry

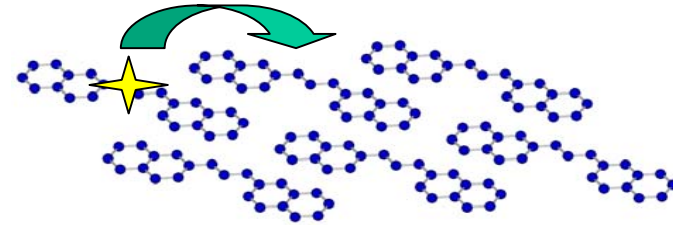


Nano-Bio

**FUTURE: Bio-inspired light-harvesting structures**

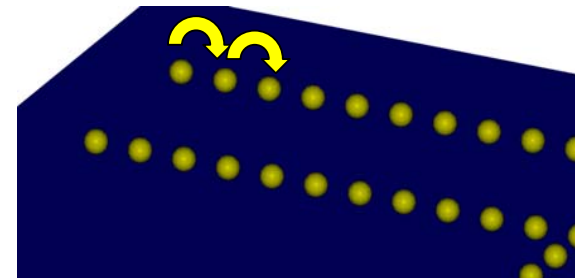
## FUTURE DIRECTIONS: Energy transfer in organic aggregates

Exciton delocalization



## FUTURE DIRECTIONS: Energy transport in nanoparticle chains

Plasmonic Wires

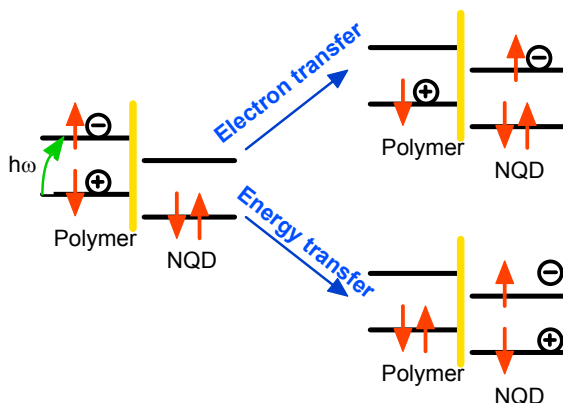




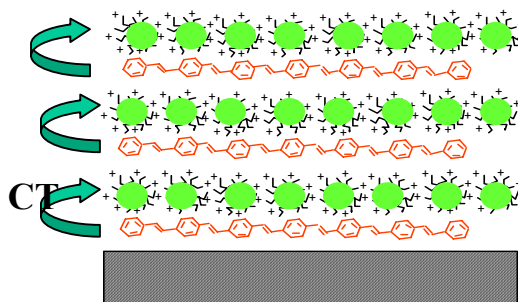
# FUTURE DIRECTIONS: Hybrid Inorganic-Organic Photonics and Electronics



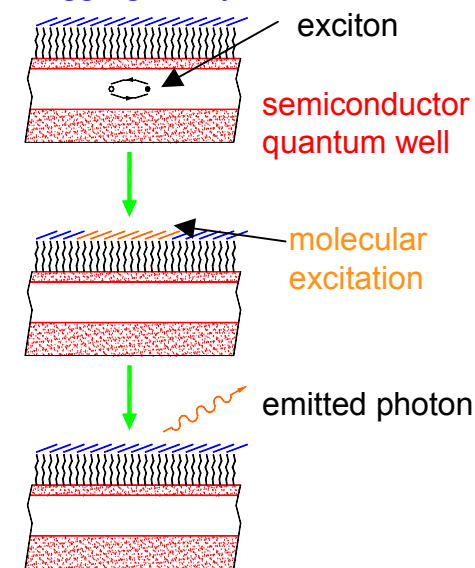
## Energy/charge transfer at organic/inorganic interfaces: light harvesting, photovoltaics, LEDs



Energy/charge transfer at Q-dot/polymer interfaces



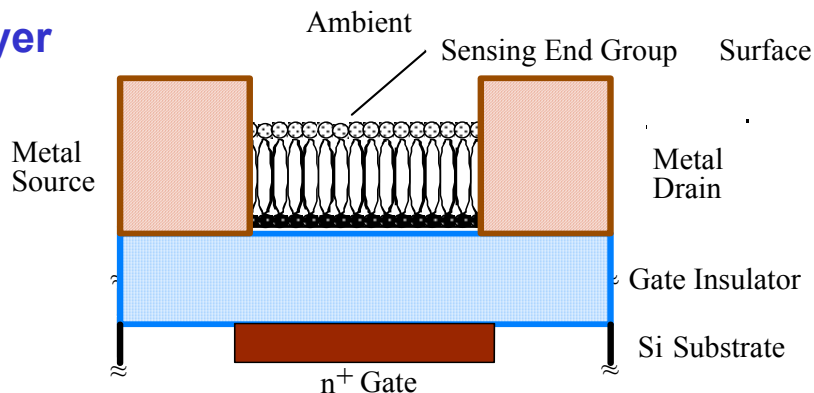
## J-aggregate layer



Exciton transfer between QWs and molecular J-aggregates

## Chem/bio-sensing: change in monolayer mobility in response to changes in environment

I. H. Campbell and D. L. Smith, *Sol. St. Phys.: Adv. Res. Appl.* **55**, 1 (2001).





# FUTURE DIRECTIONS: **Magnetic Nanostructures and Spin Interactions**



Studies of super-paramagnetic transition in Co nanoparticles

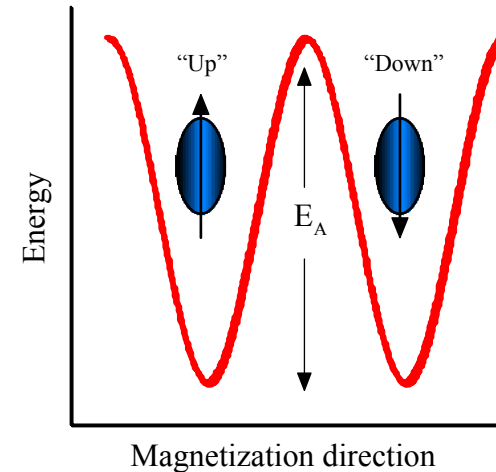
**LANL/ MIT/CalTech collaboration:**  
(Hammel, Klimov, Bawendi, Roukes)

## MIT/LANL

- Sample fabrication: size- and shape-controlled Co nanomagnets

## LANL/Caltech

- Single nanoparticle studies using MRFM: correlation between shape and magnetic anisotropies



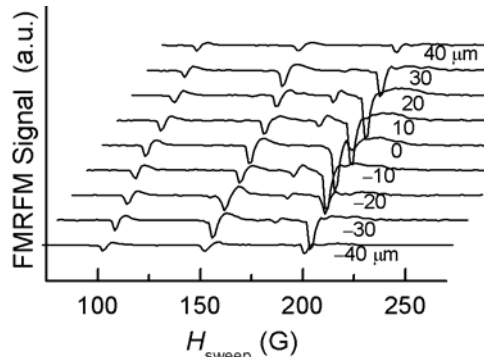
**Colloidal Co nanoparticles  
(Bawendi, MIT)**



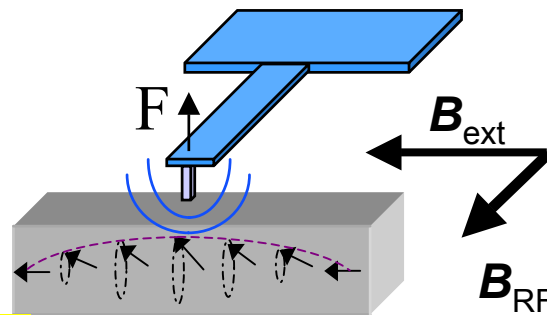
# FUTURE DIRECTIONS: **Novel Nano-Scale Probes**



## • Magnetic resonance force microscopy



**Spatially-resolved MRFM signals from YIG islands** (C. Hammel)

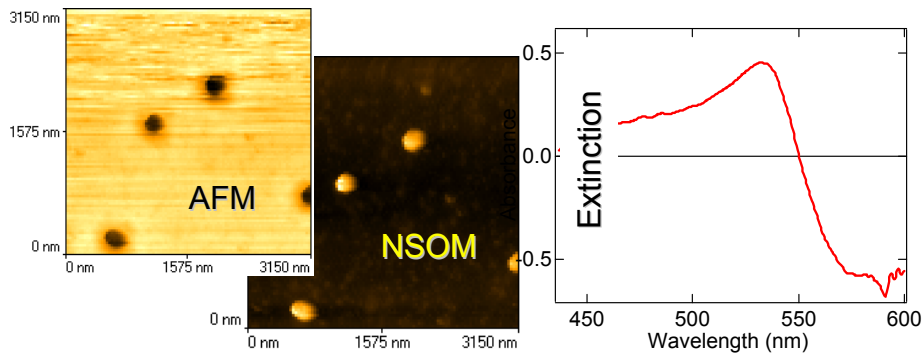


$$F = (m \cdot \nabla) B$$

Force detection (available):  
 $5 \times 10^3$  spins ( $R = 20$  nm)

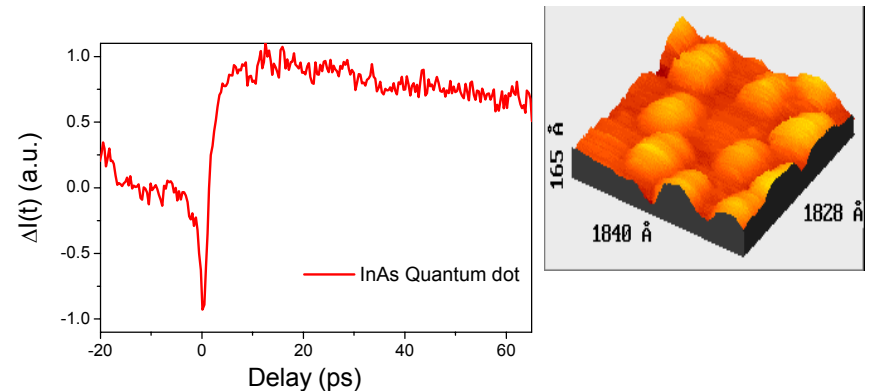
Force detection (improved):  
10 spins ( $R = 2.5$  nm)

## • Time-resolved NSOM



**Single-50-nm Au QD extinction spectrum**  
(A. Mikhailovsky and V. Klimov)

## • Ultrafast STM



**Single InP QD dynamics**  
(T. Taylor)



# New Nanoscience

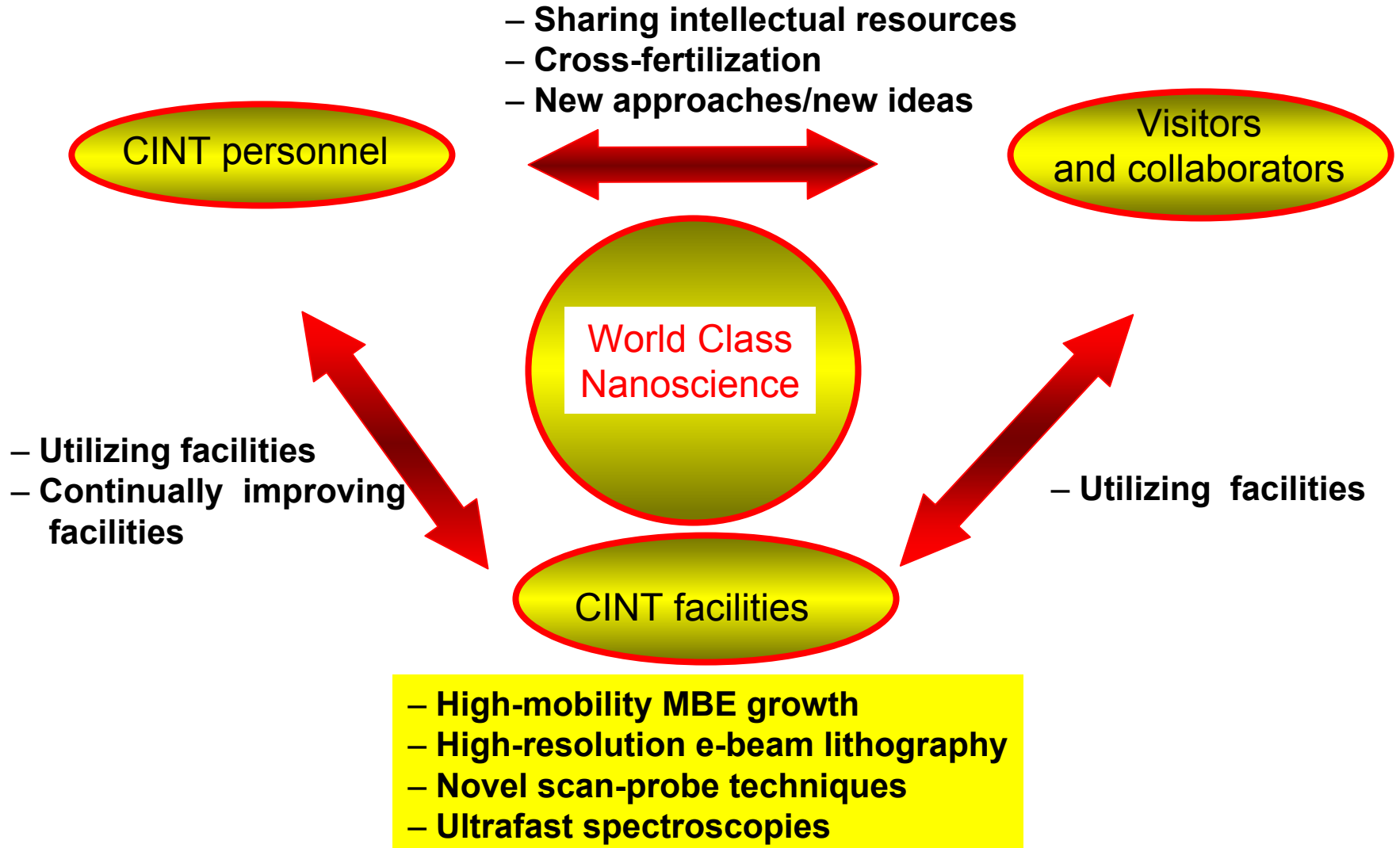
## Enabled by Novel Materials and Novel Tools



- **Comprehensive studies of nanoscale phenomena using a suite of CINT complementary tools**
  - Cooperative electronic interactions (exciton delocalization, superconductivity, cooperative magnetic interactions)
  - Coherent photonic interactions in photonic structures (photon bound states, photon tunneling, hopping, etc.)
  - Tailored electron-photon interactions in hybrid electronic/photonic structures
  - Measurements and manipulation of quantum and classical spins
  - Charge/energy transfer at nanointerfaces; single D-A pair energy/charge transfer
  - Single nano-object microscopy/spectroscopy (optical, atomic force, tunneling current, magnetic; also time-resolved)



# Collaborative Interactions Will Benefit All Parties







# How **Collaboration** Might Work



## NHMFL/ Princeton/ Sandia collaboration:

(Ye, Engel, Tsui, Simmons, Wendt, Vawter, Reno)

Microwave magnetoconductance of a 2DEG with antidot array -- FQHE edge states, composite fermions

## NHMFL/ Princeton/ Sandia:

- Sample design, mask design
- optical lithography

## Sandia:

- High mobility MBE growth (to  $10^7$  cm<sup>2</sup>/Vs)
- antidot electron beam writing
- reactive ion beam etching

## NHMFL:

- Low temperature (mK)
- high B field (to 33 T)
- high frequency (10 GHz) measurements

50 nm diameter  
antidot array

a)

